Uninterrupted Flow

$$D = \frac{V_p}{S}$$

$$V_p = \frac{V}{PHF.N.f_{HV}.f_{dp}}$$

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$$

$$SF_i = MSF_i \times N \times f_{HV} \times f_p$$

$$SV_i = SF_i \times PHF$$

$$V_j = V_0(1 + r)^n$$

HCM2010:

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84}$$

- Adjustment for Lane Width

Average Lane Width (ft)	Reduction in FFS, f_{LW} (mi/h)
≥12	0.0
≥11–12	1.9
≥10–11	6.6

- Adjustment for Lateral Clearance

Right-Side Lateral Clearance (ft)	Lanes in One Direction			
	2	3	4	≥5
≥6	0.0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

- Driver population factor

	All commuter motorist	Many unfamiliar motorists
f_{dp}	1.0	0.85

- Equivalents for General Terrain Segments:

Extended segment analysis can be applied where grades are ≤2% and ≤0.25 mi long, or where grades between 2% and 3% are ≤0.50 mi long.

Passenger car equivalency	Level terrain	Rolling terrain	Mountainous terrain
E_T	1.5	2.5	4.5
E_R	1.2	2.0	4.0

- Base Conditions:

Base (ideal) conditions	Imperial Units	SI Units
Minimum lane width	12 ft	3.6 m
Minimum right-shoulder lateral clearance	6 ft	1.8 m
Minimum median lateral clearance	2 ft	0.6 m
Minimum number of lanes	5	5
Minimum interchange spacing	2 miles	3 kilometers
Maximum level terrain	2%	2%
Percentage of passenger cars	100% passenger cars	100% passenger cars
Driver population	Commuters	Commuters

Units	Level of Service				
	A	B	C	D	E
Imperial, pc/mi/ln	0 – 11.3	11.3 – 17.7	17.7 – 25.8	25.8 – 35.4	35.4 – 45.1
SI, pc/km/ln	0 – 7	7 – 11	11 – 16	16 – 22	22 – 28

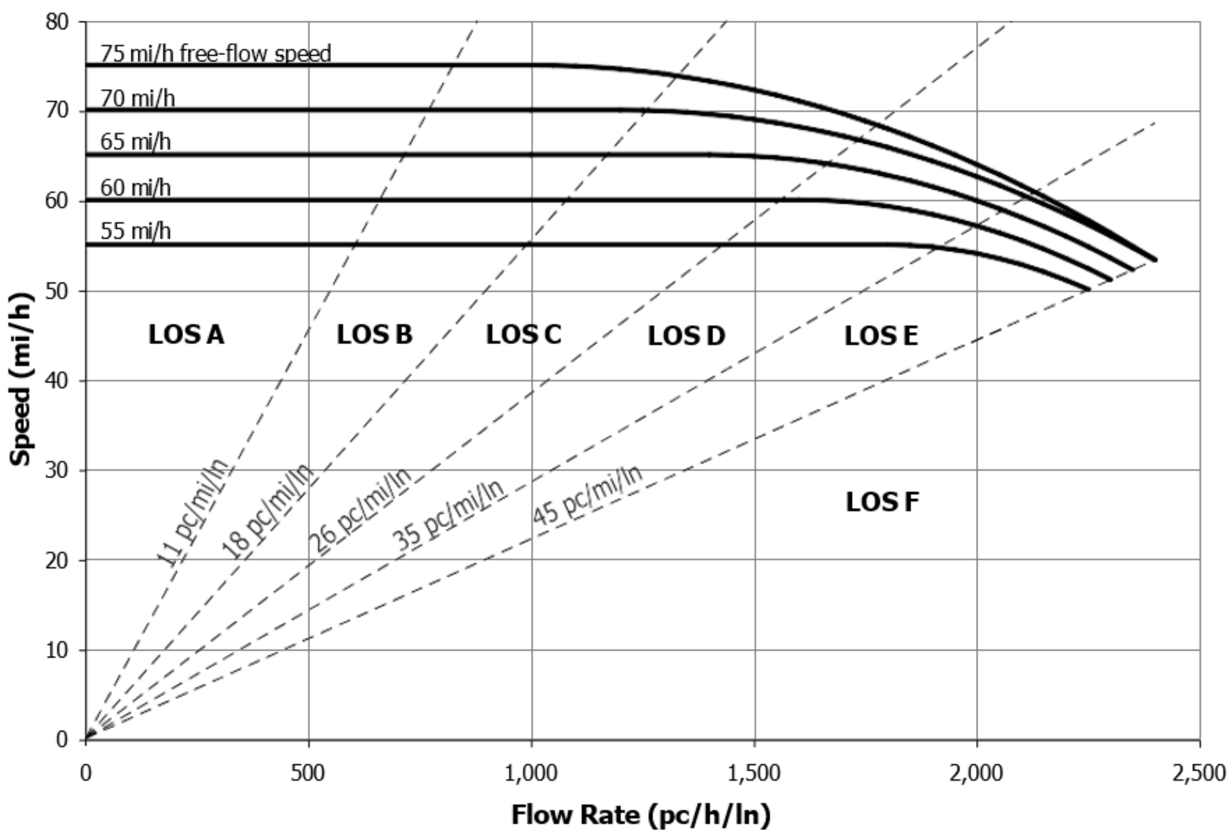
- Equivalents for Specific Upgrades:

Any freeway grade between 2% and 3% and longer than 0.5 mi or 3% or greater and longer than 0.25 mi should be considered a separate segment.

Upgrade (%)	Length (mi)	Proportion of Trucks and Buses								
		2%	4%	5%	6%	8%	10%	15%	20%	≥25%
≤2	All	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
>2–3	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.50–0.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.75–1.00	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	>1.00–1.50	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>1.50	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
>3–4	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	>0.50–0.75	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	>0.75–1.00	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	>1.00–1.50	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	>1.50	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
>4–5	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>0.50–0.75	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	>0.75–1.00	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	>1.00	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0
>5–6	0.00–0.25	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.30	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>0.30–0.50	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	>0.50–0.75	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	>0.75–1.00	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	>1.00	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
>6	0.00–0.25	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	1.0
	>0.25–0.30	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	>0.30–0.50	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	>0.50–0.75	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	>0.75–1.00	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	>1.00	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

Upgrade (%)	Length (mi)	Proportion of RVs								
		2%	4%	5%	6%	8%	10%	15%	20%	≥25%
≤2	All	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
>2–3	0.00–0.50	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	>0.50	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
>3–4	0.00–0.25	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	>0.25–0.50	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	>0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5
>4–5	0.00–0.25	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	>0.50	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
>5	0.00–0.25	4.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5
	>0.25–0.50	6.0	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.0
	>0.50	6.0	4.5	4.0	4.0	3.5	3.0	3.0	2.5	2.0

- Freeway speed-flow curves and level-of-service criteria



- LOS criteria for basic freeway segments

Criterion	LOS				
	A	B	C	D	E
			FFS = 75 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	75.0	73.8	68.3	60.9	53.3
Maximum *v/c*	0.34	0.55	0.74	0.89	1.00
Maximum flow rate (pc/h/ln)	825	1330	1775	2130	2400
			FFS = 70 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	70.0	70.0	66.7	60.3	53.3
Maximum *v/c*	0.32	0.52	0.72	0.88	1.00
Maximum flow rate (pc/h/ln)	770	1260	1735	2110	2400
			FFS = 65 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	65.0	65.0	64.0	58.8	52.2
Maximum *v/c*	0.30	0.50	0.71	0.88	1.00
Maximum flow rate (pc/h/ln)	710	1170	1665	2060	2350
			FFS = 60 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	60.0	60.0	60.0	57.1	51.1
Maximum *v/c*	0.29	0.47	0.68	0.87	1.00
Maximum flow rate (pc/h/ln)	660	1080	1560	2000	2300
			FFS = 55 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	55.0	55.0	55.0	54.7	50.0
Maximum *v/c*	0.27	0.44	0.64	0.85	1.00
Maximum flow rate (pc/h/ln)	605	990	1430	1915	2250

:

An existing six-lane divided freeway with a field-measured free-flow speed of 45 mi/h serves a peak-hour volume of 4000 veh/h, with 12% trucks and no RVs. The PHF is 0.88. The freeway has rolling terrain. What is the likely level of service for this section?

---

1. Estimate V_p:

   No recreational vehicles ➔ $P_R = 0$

   12% trucks ➔ $P_T = 0.12$

   Rolling terrain ➔ $E_T = 2.5$ (from table)

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$$

$$f_{HV} = \frac{1}{1 + 0.12(2.5 - 1) + 0(2 - 1)} = 0.847$$

   all-commuter motorist composition ➔ $f_{dp} = 1.0$

$$V_p = \frac{V}{PHF.N.f_{HV}.f_{dp}}$$

$$V_p = \frac{4000}{0.88 \times 3 \times 0.847 \times 1} = 1789\ pc/h/ln$$

2. Given S = 45 mph
3. Estimate Density:

$$D = \frac{V_p}{S}$$

$$D = \frac{1789}{45} = 39.76\ pc/mi/ln$$

4. Determine LOS:

From table LOS is E.

■■■■

A segment of four-lane freeway has a 3% upgrade that is 1500 ft long followed by a 1000-ft 4% upgrade. It has 12-ft lanes and 3-ft shoulders. The directional hourly traffic flow is 2000 vehicles with 5% large trucks and buses (no recreational vehicles). The total ramp density for this freeway segment is 2.33 ramps per mile. If the peak-hour factor is 0.90 and all of the drivers are regular users, what is the level of service of this compound-grade segment?

---

1. Estimate V_p:

$$average\ upgrade = \frac{1500 \times 3 + 1000 \times 4}{2500} = 3.4\%$$

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$$

P_T = 0.05, P_R = 0, E_T = 2 (from table use 3.4% upgrade and 2500/5280 = 0.47 mile)

$$f_{HV} = \frac{1}{1 + 0.05(2 - 1) + 0} = 0.952$$

$$V_p = \frac{V}{PHF.N.f_{HV}.f_{dp}}$$

$$V_p = \frac{2000}{0.9 \times 2 \times 0.952 \times 1} = 1167\ pc/h/ln$$

2. Estimate S:

f_{LW} = 0 and f_{LC} = 1.8 mi/h (from Tables)

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84}$$

$$FFS = 75.4 - 0 - 1.8 - 3.22 \times 2.33^{0.84} = 67\ mph$$

3. Estimate Density:

$$D = \frac{V_p}{S}$$

$$D = \frac{1167}{67} = 17.4\ pc/mi/ln$$

4. Determine LOS:

From table LOS is B.

■■■■

A six-lane freeway in a scenic area has a measured free-flow speed of 55 mi/h. The peak-hour factor is 0.80, and there are 8% large trucks and 6% recreational vehicles in the traffic stream. One upgrade is 5% and 0.5 mi long. An analyst has determined that the freeway is operating at capacity on this upgrade during the peak hour. If the peak-hour traffic volume is 3900 vehicles, what value of the driver population factor was used?

$$V_p = \frac{V}{PHF.N.f_{HV}.f_{dp}}$$

$$f_{dp} = \frac{V}{PHF.N.f_{HV}.V_p}$$

PHF: given, N: given, V: given, f_{HV}: equation, V_p: MSF at LOS E (capacity)

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$$

$P_T = 0.08$, $P_R = 0.06$, $E_T = 2$, $E_R = 3$ (from table use 5% upgrade and 0.5 mile)

$$f_{HV} = \frac{1}{1 + 0.08(2 - 1) + 0.06(3 - 1)} = 0.833$$

From table, MSF at LOS E and speed 55 mph = 2250 pc/h/ln = V_p

$$f_{dp} = \frac{3900}{0.8 \times 3 \times 0.833 \times 2250} = 0.867$$

■■■■

A four-lane freeway is located on rolling terrain and has 12-ft lanes, no lateral obstructions within 6 ft of the pavement edges, and there are two ramps within three miles upstream of the segment midpoint and three ramps within three miles downstream of the segment midpoint. The traffic stream consists of cars, buses, and large trucks (no recreational vehicles). A weekday directional peak-hour volume of 1800 vehicles (familiar users) is observed, with 700 arriving in the most congested 15-min period. If a level of service no worse than C is desired, determine the maximum number of trucks and buses that can be present in the peak-hour traffic stream.

Find f_{HV} and use it to find P_T then multiply it by the total amount of traffic.

f_{LW} = 0 and f_{LC} = 0 mi/h (base conditions) TRD = 5/6 = 0.833

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84}$$

$$FFS = 75.4 - 0 - 0 - 3.22 \times 0.833^{0.84} = 72.6 \ mph$$

$$f_{HV} = \frac{V}{V_p.PHF.N.f_{dp}}$$

$$PHF = \frac{V}{V_{15} \times 4} = \frac{1800}{700 \times 4} = 0.643$$

The demand V_p that corresponds to a level of service C and a FFS of 72.6 mi/h can be determined by interpolating the maximum flow rates for 70 mph and 75 mph. From the table, the values in question are 1735 pc/h/ln for 70 mi/h and 1775 pc/h/ln for 75 mi/h. Interpolating, we get V_p = 1755 pc/h/ln.

$$f_{HV} = \frac{1800}{1755 \times 0.643 \times 2 \times 1} = 0.797$$

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$$

P_T = ??, P_R = 0, E_T = 2.5, E_R = 2 (from table use rolling terrain)

$$0.797 = \frac{1}{1 + P_T(2.5 - 1) + 0} \rightarrow\rightarrow P_T = 0.17$$

$$n_T = V \times P_T$$

$$n_T = 1800 \times 0.17 = 306 \ trucks$$

■■■■

An old urban four-lane freeway on rolling terrain has a free flow speed of 60 mph. The traffic features a truck proportion of 7% and no RVs. The peak-hour factor PHF = 0.90. The present peak-hour demand on the facility is 2100 veh/h, and the anticipated growth is expected to be 3% per year. What will be the level of service of this road 10 years from now?

Find the service volume SV for every LOS and compare it with the volume after ten years V_{10}

$$SV_i = SF_i \times PHF$$

$$SF_i = MSF_i \times N \times f_{HV} \times f_p$$

MSF from table for FFS = 60 mph, f_{HV} from equation, N given.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$$

$P_T = 0.07$, $P_R = 0$, $E_T = 2.5$, (from table use rolling terrain)

$$f_{HV} = \frac{1}{1 + 0.07(2.5 - 1) + 0} = 0.905$$

For example, LOS A:

- MSF_A = 660 pc/h/ln from table.
- N = 2 lanes given.
- f_{HV} = 0.905 from equation.
- f_{dp} = 1 no evidence that there is many unfamiliar traffic.
- PHF = 0.9 given.

$$SF_A = 660 \times 2 \times 0.905 \times 1 = 1195\ vph$$

$$SV_A = 1195 \times 0.9 = 1075\ vph$$

Do the same for all LOSs:

Level of Service	MSF	N	f_{HV}	f_p	SF (vph)	PHF	SV (vph)
A	660	2	0.905	1	1195	0.9	1075
B	1080	2	0.905	1	1955	0.9	1759
C	1560	2	0.905	1	2824	0.9	2541
D	2000	2	0.905	1	3620	0.9	3258
E	2300	2	0.905	1	4163	0.9	3747

volume after ten years V_{10}

$$V_j = V_0(1 + r)^n \rightarrow\rightarrow\rightarrow V_{10} = 2100(1 + 0.03)^{10} = 2822\ vph$$

Since this quantity is greater than 2541 but less than 3258 (see SV column above), we conclude that the level of service after ten years will be D.

■■■■

When will the road considered in the previous problem reach breakdown, that is, when will the freeway reach level of service F if no improvements or alternative routes are implemented?

Find *n* where V_j that is larger than SV_E

$$V_j = V_0(1 + r)^n$$

SV_E = 3747 vph

$$3747 = 2100(1 + 0.03)^n$$

n = 19.6 years

■■■■

Determine the number of lanes needed to provide LOS D during the worst 15 min of the peak hour.

- Demand volume = 4,000 veh/h (one direction).
- Level terrain.
- Traffic composition: 15% trucks, 3% RVs.
- Provision of 12-ft lanes.
- Provision of 6-ft right-side lateral clearance.
- Commuter traffic (regular users).
- PHF = 0.85.
- Ramp density = 3 ramps/mi.
- Target LOS = D.

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f_{LW} = 0 and f_{LC} = 0 mi/h (base conditions) TRD = 3 ramps/mi

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84}$$

$$FFS = 75.4 - 0 - 0 - 3.22 \times 3^{0.84} = 67.3 \ mph$$

$$V_p = \frac{V}{PHF.N.f_{HV}.f_{dp}}$$

$$N = \frac{V}{PHF.V_p.f_{HV}.f_{dp}}$$

- PHF: given, V: given, f_{HV}: equation, f_{dp} = 1 no evidence that there is many unfamiliar traffic.

V_p: MSF at LOS D (from table = 2060 pc/h/ln using FFS 65 mph)

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$$

P_T = 0.15, P_R = 0.03, E_T = 1.5, E_R = 1.2 (from table use level terrain)

$$f_{HV} = \frac{1}{1 + 0.15(1.5 - 1) + 0.03(1.2 - 1)} = 0.925$$

$$N = \frac{4000}{0.85 \times 2060 \times 0.925 \times 1} = 2.51 \ lanes$$

It is not possible to build 2.51 lanes. To provide a minimum of LOS D, it will be necessary to provide 3 lanes in each direction, or a six-lane freeway.

■■■■